One-Parameter Model for the Superworld

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We review the No-Scale $\mathcal{F}$-$SU(5)$ model with extra TeV-scale vector-like flippon multiplets and its associated collider phenomenology in the search for supersymmetry at the LHC. The model framework possesses the rather unique capacity to provide a light CP-even Higgs boson mass in the favored 124–126 GeV window while simultaneously retaining a testably light SUSY spectrum that is consistent with emerging low-statistics excesses beyond the Standard Model expectation in the ATLAS and CMS multijet data.

I.   NO-SCALE $\mathcal{F}$-$SU(5)$

A.   Phenomenological Overview

We have demonstrated [1, 2] the unique phenomenological consistency and profound predictive capacity of a model dubbed No-Scale $\mathcal{F}$-$SU(5)$, resting essentially and in equal

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measure on the tripodal foundations of the $\mathcal{F}$-lipped $SU(5)$ Grand Unified Theory (GUT) [3–5], two pairs of hypothetical TeV scale vector-like supersymmetric multiplets with origins in $\mathcal{F}$-theory model building [6–10], and the dynamically established boundary conditions of No-Scale Supergravity (SUGRA) [11–15]. It appears that the No-Scale scenario, and most stringently the vanishing of the Higgs bilinear soft term B_μ, comes into its own only when applied at an elevated scale, approaching the Planck mass. $M_\mathcal{F}$, the point of the ultimate second stage $SU(5) \times U(1)_X$ unification, emerges in turn as a suitable candidate scale only when substantially decoupled from the penultimate GUT scale unification of $SU(3)_C \times SU(2)_L$ at $M_{32} \simeq 10^{16}$ GeV via the modification to the renormalization group equations (RGEs) from the extra vector-like multiplets.

We have systematically established the hyper-surface within the $\tan\beta$, top quark mass m_t, gaugino mass $M_{1/2}$, and vector-like particle mass M_V parameter volume which is compatible with the application of the simplest No-Scale SUGRA boundary conditions [11–15]. We have demonstrated that simultaneous adherence to all current experimental constraints, most importantly contributions to the muon anomalous magnetic moment $(g-2)_\mu$ [16], the branching ratio limit on $(b \to s\gamma)$ [17, 18], and the 7-year WMAP relic density measurement [19], dramatically reduces the allowed solutions to a highly non-trivial "golden strip", tightly confining $\tan\beta$, m_t, $M_{1/2}$, and M_V, effectively eliminating all extraneously tunable model parameters, where the consonance of the theoretically viable m_t range with the experimentally established value [20] may be interpreted an independently correlated "postdiction". Finally, taking a fixed Z-boson mass, we have dynamically determined the universal gaugino mass $M_{1/2}$ and fixed $\tan\beta$ via the "Super No-Scale" mechanism [21], that being the secondary minimization, at a local *minimum minimorum*, of the minimum $V_{\min}$ of the Higgs potential for the electroweak symmetry breaking (EWSB) vacuum.

This model is moreover quite interesting from a phenomenological point of view [7, 8]. The predicted vector-like particles can be observed at the Large Hadron Collider (LHC), though possibly not during the initial run. The partial lifetime for proton decay in the leading $(e|\mu)^+\pi^0$ channels falls around 5×10^{34} years [9, 10], testable at the future Hyper-Kamiokande [22] and Deep Underground Science and Engineering Laboratory (DUSEL) [23] experiments [9, 10, 24]. The lightest CP-even Higgs boson mass can be increased [25], hybrid inflation can be naturally realized, and the correct cosmic primordial density fluctuations can be generated [26].

B. The $\mathcal{F}$-lipped SU(5) GUT

Gauge coupling unification strongly suggests the existence of a GUT. In minimal super-symmetric $SU(5)$ models there are problems with doublet-triplet splitting and dimension five proton decay by colored Higgsino exchange [5]. These difficulties can be elegantly overcome in Flipped $SU(5)$ GUT models [3–5] via the missing partner mechanism [5].

Written in full, the gauge group of Flipped $SU(5)$ is $SU(5) \times U(1)_X$, which can be embedded into $SO(10)$. The generator $U(1)_{Y'}$ is defined for fundamental five-plets as $-1/3$ for the triplet members, and $+1/2$ for the doublet. The hypercharge is given by $Q_Y = (Q_X - Q_{Y'})/5$. There are three families of Standard Model (SM) fermions, whose quantum numbers under the $SU(5) \times U(1)_X$ gauge group are

$$F_i = (\mathbf{10}, \mathbf{1}), \quad \bar{f}_i = (\bar{\mathbf{5}}, -\mathbf{3}), \quad \bar{l}_i = (\mathbf{1}, \mathbf{5}), \tag{1}$$

where $i = 1, 2, 3$. To break the GUT and electroweak gauge symmetries, we introduce two pairs of Higgs fields: a pair of ten-plet Higgs for breaking the GUT symmetry, and a pair of five-plet Higgs for electroweak symmetry breaking.

$$H = (\mathbf{10}, \mathbf{1}) \quad ; \quad \overline{H} = (\overline{\mathbf{10}}, -\mathbf{1}) \tag{2}$$

$$h = (\mathbf{5}, -\mathbf{2}) \quad ; \quad \overline{h} = (\bar{\mathbf{5}}, \mathbf{2}) \tag{3}$$

A most notable intrinsic feature of the Flipped $SU(5)$ GUT is the presence of dual unification scales, with the ultimate merger of $SU(5) \times U(1)_X$ occurring subsequent in energy to the penultimate $SU(3)_C$ and $SU(2)_L$ mixing at M_{32}. In the more traditional Flipped $SU(5)$ formulations, the scale $M_{\mathcal{F}}$ has been only slightly elevated from M_{32}, larger by a factor of perhaps only two or three [27]. Our interest however, is in scenarios where the ratio $M_{\mathcal{F}}/M_{32}$ is considerably larger, on the order of 10 to 100.

Key motivations for this picture include the desire to address the monopole problem via hybrid inflation, and the opportunity for realizing true string scale gauge coupling unification in the free fermionic model building context [6, 28], or the decoupling scenario in F-theory models [7, 8]. We have previously also considered the favorable effect of such considerations on the decay rate of the proton [9, 10]. Our greatest present interest however, is the effortless manner in which the elevation of the $SU(5) \times U(1)_X$ scale salvages the dynamically established boundary conditions of No-Scale Supergravity. Being highly predictive, these

conditions are thus also intrinsically highly constrained, and notoriously difficult to realize generically.

C. $\mathcal{F}$-theory Vector-Like Multiplets

We have introduced additional vector-like particle multiplets derived within the $\mathcal{F}$-theory [6] model building context to address the "little hierarchy" problem, altering the β-coefficients of the renormalization group to dynamically elevate the secondary $SU(5) \times U(1)_X$ unification at $M_{\mathcal{F}}$ to near the Planck scale, while leaving the $SU(3)_C \times SU(2)_L$ unification at M_{32} close to the traditional GUT scale. In other words, one obtains true string-scale gauge coupling unification in free fermionic string models [6, 28] or the decoupling scenario in F-theory models [7, 8]. To avoid a Landau pole for the strong coupling constant, we are restricted around the TeV scale to one of the following two multiplet sets [6].

$$Z1 : \; \left(XF_{(\mathbf{10,1})} \equiv (XQ, XD^c, XN^c), \; \overline{XF}_{(\overline{\mathbf{10}}, -\mathbf{1})} \right)$$
$$Z2 : \; \left(XF, \; \overline{XF}, Xl_{(\mathbf{1}, -\mathbf{5})}, \; \overline{Xl}_{(\mathbf{1,5})} \equiv XE^c \right) \tag{4}$$

In the prior, XQ, XD^c, XE^c, XN^c have the same quantum numbers as the quark doublet, the right-handed down-type quark, charged lepton, and neutrino, respectively. We have argued [2] that the feasibly near-term detectability of these hypothetical fields in collider experiments, coupled with the distinctive flipped charge assignments within the multiplet structure, represents a smoking gun signature for Flipped $SU(5)$, and have thus coined the term *flippons* to collectively describe them. In this paper, we consider only the $Z2$ set, although discussion for the $Z1$ set, if supplemented by heavy threshold corrections, can be similar.

We emphasize that the specific representations of vector-like fields which we currently employ have been explicitly constructed within the local F-theory model building context [7, 8]. However, the mass of these fields, and even the fact of their existence, is not mandated by the F-theory, wherein it is also possible to realize models with only the traditional Flipped (or Standard) $SU(5)$ field content. We claim only an inherent consistency of their conceptual origin out of the F-theoretic construction, and take the manifest phenomenological benefits which accompany the elevation of $M_{\mathcal{F}}$ as justification for the greater esteem which we hold for this particular model above other alternatives.

D.   No-Scale Supergravity

The Higgs boson, being a Lorentz scalar, is not stable in the SM against quadratic quantum mass corrections which drive it toward the dominant Planck scale, some seventeen orders of magnitude above the value required for consistent EWSB. Supersymmetry naturally solves this fine tuning problem by pairing the Higgs with a chiral spin-1/2 "Higgsino" partner field, and following suit with a corresponding bosonic (fermionic) superpartner for all fermionic (bosonic) SM fields, introducing the full set of quantum counter terms. Localizing the supersymmetry (SUSY) algebra, which includes the generator of spacetime translations (the momentum operator), induces general coordinate invariance, producing the supergravity (SUGRA) theories.

Since we do not observe mass degenerate superpartners for the known SM fields, SUSY must itself be broken around the TeV scale. In the traditional framework, supersymmetry is broken in the hidden sector, and the effect is mediated to the observable sector via gravity or gauge interactions. In GUTs with minimal gravity mediated supersymmetry breaking, called mSUGRA, one can fully characterize the supersymmetry breaking soft terms by four universal parameters (gaugino mass $M_{1/2}$, scalar mass M_0, trilinear coupling A, and the low energy ratio $\tan\beta$ of up- to down-type Higgs VEVs, plus the sign of the Higgs bilinear mass term μ. The μ term and its bilinear soft term B_μ are determined by the Z-boson mass M_Z and $\tan\beta$ after the electroweak (EW) symmetry breaking.

No-Scale Supergravity was proposed [11–15] to address the cosmological flatness problem, and defined as the subset of supergravity models which satisfy the following three constraints [11]: (i) The vacuum energy vanishes automatically due to the suitable Kähler potential; (ii) At the minimum of the scalar potential, there are flat directions which leave the gravitino mass $M_{3/2}$ undetermined; (iii) The super-trace quantity $\mathrm{Str}\mathcal{M}^2$ is zero at the minimum. Without this, the large one-loop corrections would force $M_{3/2}$ to be either zero or of Planck scale. The defining Kähler potential [14]

$$K \; = \; -3\mathrm{ln}(T + \overline{T} - \sum_i \overline{\Phi}_i \Phi_i) \; , \tag{5}$$

automatically satisfies the first two conditions, while the third is model dependent and can always be satisfied in principle [29].

In Eq. (5), T is a modulus field, while the Φ_i are N_C scalar matter fields which parameter-

ize the coset space $SU(N_C+1, 1)/(SU(N_C+1) \times U(1))$. The scalar potential is automatically positive semi-definite, and has a flat direction along the T field. The non-compact structure of the symmetry implies that the classical vacuum is not only constant but actually identical to zero. Moreover, the simplest No-Scale boundary conditions $M_0 = A = B_\mu = 0$ are dynamically established, while $M_{1/2} > 0$ is allowed, and indeed required for SUSY breaking. A one-parameter model of similar form has been much studied in the past [30–32] (For a review, see [33]). The CP violation problem and the flavor changing neutral current problems are automatically solved in turn. All low energy scales are dynamically generated by quantum corrections, $i.e.$ running under the RGEs, to the classically flat potential.

E.   The Stringy Super No-Scale Mechanism

The fiercely reductionist No-Scale picture inherits an associative weight of motivation from its robustly generic and natural appearance, for example, in the compactification of the weakly coupled heterotic string theory [34], compactification of M-theory on S^1/Z_2 at the leading order [35], and potentially also directly in F-theory models [36–39].

In the simplest stringy No-Scale SUGRA, the Kähler modulus T, a characteristic of the Calabi-Yau manifold, is the single relevant modulus field, the dilaton coupling being irrelevant. The F-term of T generates the gravitino mass $M_{3/2}$, which is proportionally equivalent to $M_{1/2}$. Exploiting the simplest No-Scale boundary condition at $M_{\mathcal{F}}$ and running from high energy to low energy under the RGEs, there can be a secondary minimization, or $minimum\ minimorum$, of the minimum of the Higgs potential $V_{\min}$ for the EWSB vacuum. Since $V_{\min}$ depends on $M_{1/2}$, the universal gaugino mass $M_{1/2}$ is consequently dynamically determined by the equation $dV_{\min}/dM_{1/2} = 0$, aptly referred to as the "Super No-Scale" mechanism; We have argued by the combined action of this mechanism, the transmutative role of the the RGEs, and the stabilizing counter-balance of supersymmetry, that No-Scale $\mathcal{F}$-$SU(5)$ addresses the various aspects of the gauge hierarchy problem [21].

The three parameters M_0, A, B_μ are once again identically zero at the boundary because of the defining Kähler potential, and are thus known at all other scales as well by the RGEs. The minimization of the Higgs scalar potential with respect to the neutral elements of both SUSY Higgs doublets gives two conditions, the first of which fixes the magnitude of μ. The second condition, which would traditionally be used to fix B_μ, instead here enforces a

consistency relationship on the remaining parameters, being that B_μ is already constrained.

In general, the $B_\mu = 0$ condition gives a hypersurface of solutions cut out from a very large parameter space. If we lock all but one parameter, it will give the final value. If we take a slice of two dimensional space, as has been described, it will give a relation between two parameters for all others fixed. In a three-dimensional view with B_μ on the vertical axis, this curve is the "flat direction" line along the bottom of the trench of $B_\mu = 0$ solutions. In general, we must vary at least two parameters rather than just one in isolation, in order that their mutual compensation may transport the solution along this curve. The most natural first choice is in some sense the pair of prominent unknown inputs $M_{1/2}$ and $\tan\beta$, as demonstrated in Ref. [21].

It must be emphasized that the $B_\mu = 0$ No-Scale boundary condition is the central agent affording this determination, as it is the extraction of the parameterized parabolic curve of solutions in the two compensating variables which allows for a localized, bound nadir point to be isolated by the Super No-Scale condition, dynamically determining *both* parameters. The background surface of $V_{\min}$ for the full parameter space outside the viable $B_\mu = 0$ subset is, in contrast, a steadily inclined and uninteresting function. In our prior study, the local *minimum minimorum* of $V_{\min}$ for selected inputs of M_V and m_t was taken to dynamically establish the values of $M_{1/2}$ and $\tan\beta$. Although $M_{1/2}$ and $\tan\beta$ have no *directly* established experimental values, they are severely indirectly constrained by phenomenology in the context of this model [1, 2]. It is highly non-trivial that there should be a strong accord between the top-down and bottom-up perspectives, but this is indeed precisely what has been observed [21].

II. $\mathcal{F}$-$SU(5)$ **SUSY MULTIJETS AT THE** $\sqrt{s} = 7$ **TEV LHC**

The $\mathcal{F}$-$SU(5)$ model space is bounded primarily by a set of "bare-minimal" experimental constraints distinguished by a great longevity of relevance, as defined in Ref. [40]. These include the top quark mass $172.2 \text{ GeV} \leq m_t \leq 174.4 \text{ GeV}$, 7-year WMAP cold dark matter relic density $0.1088 \leq \Omega_{\text{CDM}}h^2 \leq 0.1158$ [19], and precision LEP constraints on the SUSY mass content. We further append to this classification an adherence to the defining high-scale boundary conditions of the model. In light of recent developments, the favored parameter space may be further circumscribed by the demands of a 124–126 GeV Higgs boson mass.

The surviving region is comprised of a narrow strip of space confined to $400 \leq M_{1/2} \leq 900$ GeV, $19.4 \leq \tan\beta \leq 23$, and $950 \leq M_V \leq 6000$ GeV. The border at the minimum $M_{1/2} = 400$ GeV is required by the LEP constraints, while the maximum boundary at $M_{1/2} = 900$ GeV prevents a charged stau LSP at around $\tan\beta \cong 23$. In the bulk of the model space the lightness of the stau is leveraged to facilitate an appropriate dark matter relic density via stau-neutralino coannihilation.

The convergence of the predicted $\mathcal{F}$-$SU(5)$ Higgs mass with the collider measured value is achieved through contributions to the lightest CP-even Higgs boson mass from the flippons, calculated from the RGE improved one-loop effective Higgs potential approach [41, 42]. The mechanism for the serendipitous mass shift is a pair of Yukawa interaction terms between the Higgs and vector-like flippons in the superpotential, resulting in a 3–4 GeV upward shift in the Higgs mass to the experimentally measured range [43]. Using the relevant shift in the Higgs mass-square as approximated in Refs. [25, 43], which implements a leading dependence of the flippon mass M_V, larger shifts correspond to lighter vector-like flippons. This flippon induced mechanism operates in synthesis with the top quark mass, whose elevation similarly raises the non-flippon contributed Higgs mass. The cumulative result is a very narrow strip of model space, with the lower strip boundary truncated by the upper top quark mass extremity, and the upper strip boundary situated at the minimum Higgs mass of 124 GeV, conveniently establishing a stable, thin band of experimentally viable points with which to explore new physics.

The same flippon induced perturbation to the RGE unification structure of $\mathcal{F}$-$SU(5)$ that was responsible for facilitating a consistent application of the No-Scale boundary conditions near the Planck mass also produces a key phenomenological signature. The flat RGE evolution of the $SU(3)_C$ gaugino mass M_3, which mirrors the flatness of the β-coefficient $b_3 = 0$, suppresses the standard logarithmic mass enhancement at low-energy and yields a SUSY spectrum $M(\widetilde{t}_1) < M(\widetilde{g}) < M(\widetilde{q})$ where the light stop $\widetilde{t}_1$ and gluino $\widetilde{g}$ are both less massive than all other squarks. This highly unusual hierarchy produces a distinct event topology initiated by the pair-production of heavy first or second generation squarks $\widetilde{q}$ and/or gluinos in the hard scattering process, with the heavy squark likely to yield a quark-gluino pair $\widetilde{q} \to q\widetilde{g}$. The gluino then has only two main channels available in the cascade decay, $\widetilde{g} \to \widetilde{t}_1\bar{t}$ or $\widetilde{g} \to q\bar{q}\widetilde{\chi}_1^0$, with $\widetilde{t}_1 \to t\widetilde{\chi}_1^0$ or $\widetilde{t}_1 \to b\widetilde{\chi}_1^\pm$. As $M_{1/2}$ increases, the stop-top channel becomes dominant, ultimately reaching 100% for $M_{1/2} \geq 729$ GeV. For $M_{1/2} < 729$ GeV,
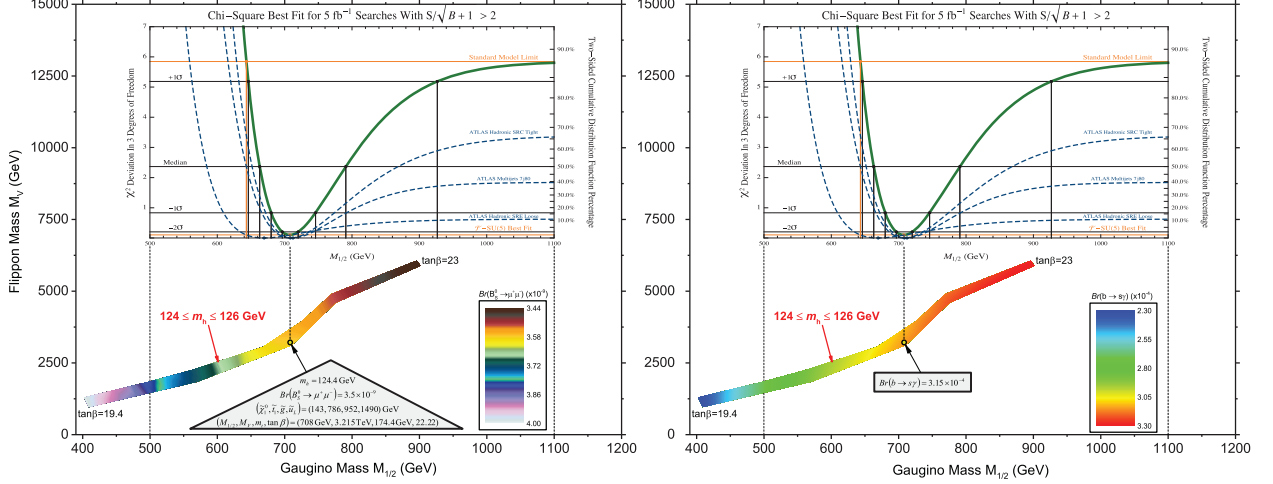
FIG. 1: We depict the experimentally viable parameter space of No-Scale $\mathcal{F}$-$SU(5)$ as a function of the gaugino mass $M_{1/2}$ and flippon mass M_V. The surviving model space after application of the bare-minimal constraints of Ref. [40] and Higgs boson mass calculations of Ref. [43] is illustrated by the narrow strip with the smoothly contoured color gradient. The gradient represents the total branching ratio (SM+SUSY) of the B-decay process $B_S^0 \to \mu^+\mu^-$ (left), and the total branching ratio (SM+SUSY) of $b \to s\gamma$ (right). The inset diagrams (with linked horizontal scale) are the multi-axis cumulative χ^2 fitting of Ref. [44], depicting the best SUSY mass fit and Standard Model limit of only those ATLAS and CMS SUSY searches exhibiting a signal significance of $S/\sqrt{B+1} > 2$. The best fit benchmark of Ref. [44] is highlighted at $M_{1/2} = 708$ GeV, with $m_h = 124.4$ GeV.

both avenues have sufficient branching fractions to produce observable events at the LHC. Each gluino produces 2–6 hadronic jets, with the maximum of six jets realized in the gluino-mediated stop decay, so that a single gluino-gluino pair-production event can net 4–12 jets. After further fragmentation processes, the final event is characterized by a definitive SUSY signal of high-multiplicity jets.

The most robust test of any supersymmetric model is the prediction of a unique signature plainly accounting for observed anomalies in collider data. The exceptional mass ordering in No-Scale $\mathcal{F}$-$SU(5)$ provides a distinctive marker at the LHC, since multijet events are expected to dominate a probed $\mathcal{F}$-$SU(5)$ framework. We first suggested in March 2011 [45, 46] that SUSY in an $\mathcal{F}$-$SU(5)$ universe would become manifest at the colliders in high-multiplicity jet events, extending this initial study in Refs. [43, 44, 47–52]. The first ample accumulation of multijet data was released by the collaborations later in 2011 in Refs. [53–

55], based upon 1 fb^{-1} of luminosity. Though the number of events remaining after the collaboration data cuts was less than ten, there did appear small but curious excesses beyond the SM estimates in these searches targeting multijet events. The most prominent examples came from ATLAS, where the 7j80 (≥ 7 jets and jet $p_T > 80$ GeV) search of Ref. [55] and High Mass (≥ 4 jets and jet $p_T > 80$ GeV) search of Ref. [54] displayed interesting event production over the data-driven background estimates. Employing the signal significance metric $S/\sqrt{B+1}$, we computed a value of 1.1 for 7j80 and 1.3 for the High Mass search. Despite the weak signal, reasonably attributable to statistical fluctuations, No-Scale $\mathcal{F}$-$SU(5)$ provided a neat and efficient explanation for the minor over-productions in these two searches. Despite the long odds at that time, those clean fits prompted us to extrapolate from the ATLAS published statistics of Refs. [54, 55] to predict signal strengths of $S/\sqrt{B+1} = 1.9$ for 7j80 and $S/\sqrt{B+1} = 3.0$ for the High Mass [51] search in the forthcoming 5 fb^{-1} data set at 7 TeV, assuming a legitimate physics origin for the intriguing over-production.

We provided a detailed analysis of the ATLAS and CMS 5 fb^{-1} observations at the 7 TeV LHC in Ref. [44], focused on those search strategies where the signal significance was strongest and the largest number of events had accumulated, imposing $S/\sqrt{B+1} > 2.0$ as a minimal boundary. Strikingly, the 7j80 [56] search and the composite successors to the High Mass search were the only 5 fb^{-1} strategies to surmount this significance hurdle. To elaborate, ATLAS essentially segregated the former High Mass ≥ 4 jet SUSY search of Ref. [54] into three separate searches of 4 jets, 5 jets, and 6 jets for the latter study, intended to isolate the $\widetilde{g}\widetilde{g}$, $\widetilde{q}\widetilde{g}$, and $\widetilde{q}\widetilde{q}$ 0-lepton channels via $\widetilde{q} \to q\widetilde{g}$ and $\widetilde{g} \to q\overline{q}\widetilde{\chi}_1^0$ [57]. In addition to the ATLAS 7j80 [56], these ATLAS 4-jet and 6-jet searches of Ref. [57], referred to as SRC Tight and SRE Loose, respectively, were the only other 5 fb^{-1} searches to achieve $S/\sqrt{B+1} > 2.0$ in all the ATLAS and CMS 5 fb^{-1} studies analyzed at that time. Granting that the 1 fb^{-1} data sample is a subset of the 5 fb^{-1} data, the signal strength nevertheless expanded in the precise proportionality expected. The final 5 fb^{-1} 7 TeV ATLAS observations computed signal significances of $S/\sqrt{B+1} = 2.1$ for 7j80 [56], $S/\sqrt{B+1} = 3.2$ for SRC Tight (4j) [57], and $S/\sqrt{B+1} = 2.6$ for SRE Loose (6j) [57], in line with our predictions and very consistent with the signal growth expected to be observed in an $\mathcal{F}$-$SU(5)$ universe.

This enlarged signal strength simultaneously presented a golden opportunity to derive a best fit SUSY mass to the 5 fb^{-1} data through a χ^2 fitting procedure. We demonstrated [44]

clear internal consistency in the $\mathcal{F}\text{-}SU(5)$ mass scale favored by the various search windows, in addition to the described correlation across time in the signal growth. This analysis favored sparticle masses of $m_{\widetilde{\chi}_1^0} = 143$ GeV, $m_{\widetilde{t}_1} = 786$ GeV, $m_{\widetilde{g}} = 952$ GeV, and $m_{\widetilde{u}_L} = 1490$ GeV, complementing a Higgs mass of $m_h = 124.4$ GeV at the $M_{1/2} = 708$ GeV well of the 5 fb^{-1} multi-axis cumulative χ^2 curve, combining the 7j80, SRC Tight, and SRE Loose search channels. To exemplify this best fit at the χ^2 minimum, we chose an $M_{1/2} = 708$ GeV point as our standing favored benchmark [44]. The superimposed cumulative χ^2 curve of Ref. [44] visibly showcases how the ATLAS 7j80, SRC Tight, and SRE Loose over-productive search strategies illuminate the $\mathcal{F}\text{-}SU(5)$ model space as naturally conforming to the collider observations. By lowering the minimum threshold for signal significance to $S/\sqrt{B+1} > 1.0$, the CMS 5 fb^{-1} MT2 search strategy [58] was included into our 5 fb^{-1} multi-axis χ^2 fitting in Ref. [52] along with an additional ATLAS search, namely the 8j55 case from Ref. [56]. It was demonstrated in this manner that further non-trivial correlations exist between the mass scale favored by independently productive ATLAS and CMS SUSY searches, bolstering the case against attribution of the excesses to random statistical fluctuations.

The data observations for the ATLAS multijet searches discussed here have shown a very natural progression from 1 fb^{-1} to 5 fb^{-1}. In fact, the $S/\sqrt{B+1} \sim 3$ signal significance of the combined ATLAS 5 fb^{-1} multijet searches, which we can consider to be about 3σ, is near the same signal level as the Higgs boson after 5 fb^{-1} at 7 TeV. With the Higgs boson now at the discovery threshold of 5σ in the first 8 TeV data tranche, it would only be fitting if the ATLAS multijet SUSY searches continued to track the Higgs signal strength. Looking forward and preparing for potentially more significant SUSY production as we shift to forthcoming larger LHC beam collision energies and hence greater numbers of statistics, we transition here to a more appropriate metric for measuring signal strength in the presence of larger excess event production beyond expectations, $2 \times (\sqrt{S+B} - \sqrt{B})$. We employ the background statistics derived by the ATLAS Collaboration for 5 fb^{-1} at 7 TeV from Ref. [56], though to determine an estimate of the SM background for 8 TeV, we scale up these ATLAS statistics using the same factor observed in our Monte Carlo for $\mathcal{F}\text{-}SU(5)$ simulations. This estimator, while serving our limited scope here satisfactorily, can only be as reliable as the expectation of statistical, dynamic and procedural stability across the transition in energy, luminosity and model. We further assume here a static data cutting strategy between the ATLAS 7 and 8 TeV multijet searches. We indeed project that there

should be a visible multijet signal strength sufficient for SUSY discovery in the isolated 15 fb^{-1} 8 TeV data, expected to be recorded in 2012 and processed in 2013, if the existing signal in the 5 fb^{-1} 7 TeV data is legitimately and wholly attributable to new physics. More precisely, assuming no important modifications to the background calibration procedures by ATLAS, we can project the 7j80 SUSY search tactics of Ref. [56] to yield a signal significance of $2 \times (\sqrt{S+B} - \sqrt{B}) \sim 6$ for 15 fb^{-1} at 8 TeV, and $2 \times (\sqrt{S+B} - \sqrt{B}) \sim 7$–8 for the SRC-Tight and SRE-Loose search strategies of Ref. [57]. Although potentially quite susceptible to large statistical fluctuation, these rather strong signal projections nonetheless indicate that a probing of the $\mathcal{F}$-$SU(5)$ framework at the LHC could indeed yield further tantalizing, and possibly convincing, evidence that nature herself is fundamentally supersymmetric. The summation of the 5 fb^{-1} of 7 TeV data to the 8 TeV data only improves the signal significance modestly. Moreover, the presence of excess events in the 15 fb^{-1} ATLAS multijet searches at 8 TeV will resoundingly indicate that random background anomalies are not the source of the 7 TeV multijet over-production. We find the predictable evolution of our SUSY exploration from the initial 1 fb^{-1} at 7 TeV to the 5 fb^{-1} at 7 TeV to warrant such positive speculation as we move forward to the 15 fb^{-1} at 8 TeV.

III.   PRIMORDIAL SYNTHESIS

We now seek to synthesize the strip of model space supporting an $m_h \sim 125$ GeV Higgs boson [59–61] with the amalgamation of complementary supersymmetry experiments, including our 8 TeV conclusions of Ref. [62]. We begin with the original components of our Golden Strip [2, 40, 49], which are the key rare process limits on $Br(b \rightarrow s\gamma)$, $Br(B_S^0 \rightarrow \mu^+\mu^-)$, and Δa_μ on $(g-2)_\mu$ of the muon. For $b \rightarrow s\gamma$, we use the latest world average of the Heavy Flavor Averaging Group (HFAG), BABAR, Belle, and CLEO, which is $(3.55 \pm 0.24_{\text{exp}} \pm 0.09_{\text{model}}) \times 10^{-4}$ [17]. An alternate approach to the average [63] yields a slightly smaller central value, but also a lower error, suggesting $Br(b \rightarrow s\gamma) = (3.50 \pm 0.14_{\text{exp}} \pm 0.10_{\text{model}}) \times 10^{-4}$. See Ref. [64] for recent discussion and analysis. The theoretical SM contribution at the next-to-next-to-leading order (NNLO) is estimated at $Br(b \rightarrow s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ [18] and $Br(b \rightarrow s\gamma) = (2.98 \pm 0.26) \times 10^{-4}$ [65]. The addition of these errors in quadrature provides the 2σ limits of $2.86 \times 10^{-4} \leq Br(b \rightarrow s\gamma) \leq 4.24 \times 10^{-4}$. The recent precision improved LHCb constraints on the B-decay process

$B_S^0 \to \mu^+\mu^-$ of $Br(B_S^0 \to \mu^+\mu^-) < 4.5(3.8) \times 10^{-9}$ at the 95% (90%) confidence level [66] are employed here, though we find the entire viable $\mathcal{F}$-$SU(5)$ parameter space lies comfortably below this upper limit [59]. The new calculations of the tenth-order QED terms for the theoretical prediction of $(g-2)_\mu$ engenders a favorable shift in Δa_μ in the context of $\mathcal{F}$-$SU(5)$, where we apply the 2σ uncertainty of $6.6 \times 10^{-10} \le \Delta a_\mu \le 41.4 \times 10^{-10}$. The $b \to s\gamma$ and $(g-2)_\mu$ effects reside at their lower boundaries in the 125 GeV Higgs boson strip, as they exert pressure in opposing directions on $M_{1/2}$ since the leading gaugino and squark contributions to $Br(b \to s\gamma)$ admit an opposite sign to the Standard Model term and Higgs contribution. On the contrary, the effect is additive for the non-Standard Model contribution to Δa_μ, establishing an upper limit on $M_{1/2}$. The SUSY contribution to $Br(b \to s\gamma)$ cannot be excessively large such that the Standard Model effect becomes minimized, thus necessitating a sufficiently large, or lower bounded, $M_{1/2}$.

The computation of the rare-decay processes for all points in the 125 GeV Higgs boson strip are illustrated in Figure (2). We implement a range on the strong coupling constant of $0.1145 \le \alpha_s(M_Z) \le 0.1172$ that tightly envelopes the central value of $\alpha_s(M_Z) = 0.1161$ that is supported by recent direct observations [67], introducing a modest uncertainty onto the calculation of each curve in Figure (2), represented by the contour thickness in each pane. All SUSY particle masses, Higgs boson masses, relic densities, and constraints are computed with `MicrOMEGAs 2.4` [68], applying the proprietary modification of the `SuSpect 2.34` [69] codebase to run the flippon-enhanced RGEs. In Figure (2), the boxed curve segments depict the experimentally observed 2σ values.

We now expand our original Golden Strip to encompass proton decay and dark matter detection experiments. The $p \to e^+\pi^0$ mode in $\mathcal{F}$-$SU(5)$ is depicted in Figure (2), indicative of the large pervasive uncertainty propagated into the proton lifetime from the large QCD uncertainties in $\alpha_s(M_Z)$. We apply the Super-Kamiokande established lower bound of 1.4×10^{34} years at the 90% confidence level for the partial lifetime in the $p \to e^+\pi^0$ mode [70]. For the spin-independent dark matter-nucleon cross section, the XENON100 experiment has probed down to 2×10^{-9} pb (2×10^{-45} cm^2) for a WIMP mass of 55 GeV [71], also at the 90% confidence level. The No-Scale $\mathcal{F}$-$SU(5)$ viable model space shown in Figure (2) lies entirely below this upper bound [72].

The observation of a 130 GeV gamma-ray line with annihilation cross-section $\langle \sigma v \rangle \sim 10^{-27}$ cm^3/s [73] emanating from our galactic center by the FERMI-LAT Space Telescope
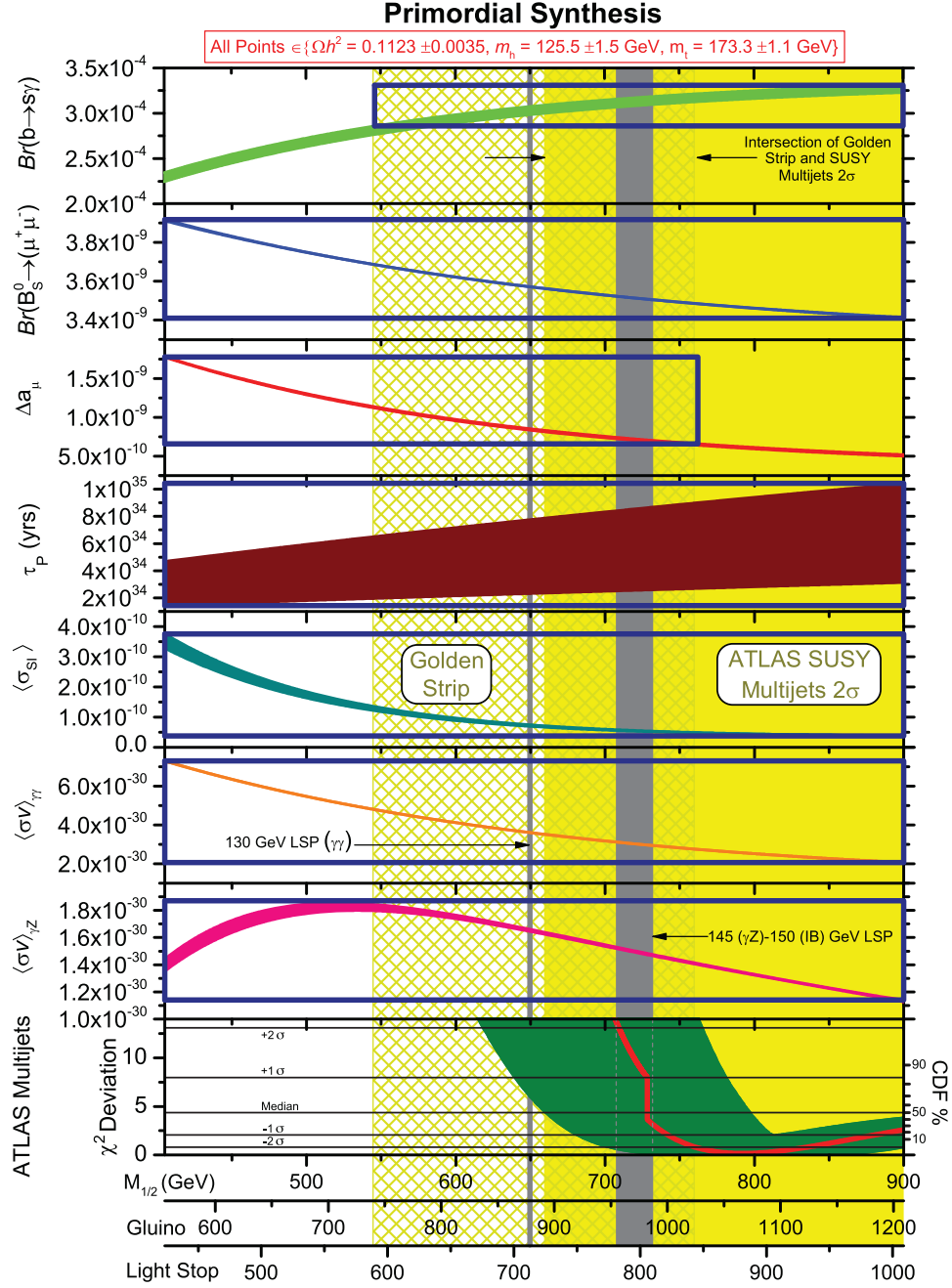
FIG. 2: Primordial Synthesis of all currently progressing experiments searching for physics beyond the Standard Model. All points depicted on each curve satisfy the conditions $0.1088 \leq \Omega h^2 \leq 0.1158$, $124 \leq m_h \leq 127$ GeV, and $172.2 \leq m_t \leq 174.4$ GeV. Each curve thickness represents an uncertainty on the strong coupling constant $0.1145 \leq \alpha_s(M_Z) \leq 0.1172$ (excluding the χ^2 pane). The multi-axis χ^2 deviation in the bottom pane comprises an uncertainty derived from an increase and decrease by a factor of 2 around the χ^2 computed on the nominal number of $\mathcal{F}$-$SU(5)$ events surviving all cuts (nominal value shown in center of shaded curve).

has initiated investigations into whether such a monochromatic line could be attributed to dark matter annihilations, an argument amplified by the lack of any known astrophysical source capable of producing a tantamount signature. The lightest neutralino mass at the minimum of the χ^2 fit to the ATLAS multijet and light stop excesses is $m_\chi = 145$ GeV, clearly highlighted as the benchmark model in Figure (1). Conjecturing the observed photon line originates from neutralino annihilations into a Z-boson and gamma-ray via $\widetilde{\chi}\widetilde{\chi} \to Z\gamma$, we can compute the kinematics for a non-relativistic lightest neutralino $\widetilde{\chi}_1^0$ as

$$E_\gamma = M_\chi - \frac{M_Z^2}{4M_\chi} \,, \tag{6}$$

which gives

$$M_\chi = \frac{E_\gamma}{2} \left[1 + \sqrt{1 + \left(\frac{M_Z}{E_\gamma} \right)^2} \right] \tag{7}$$

Using $E_\gamma \simeq 130$ GeV and $M_Z = 91.187$ GeV, we arrive at

$$M_\chi = 144.4 \text{ GeV} \,,$$

which is consistent with the No-Scale $\mathcal{F}\text{-}SU(5)$ lightest neutralino mass of $M_\chi = 145$ GeV at the best fit to the multijet and light stop excesses at the LHC *and* generates an $m_h \simeq 125.5$ GeV Higgs boson mass. The fit is near $m_\chi \sim 150$ GeV for internal bremsstrahlung [74]. We allow for the potential combination of all of the above that could land a WIMP mass somewhere in the range $130 \lesssim m_\chi \lesssim 150$ GeV, and as a consequence, we annotate the 130-150 GeV LSP mass region in Figure (2). The most recent FERMI-LAT Collaboration upper bound on the gamma-ray annihilation cross section is $\langle \sigma v \rangle \sim 10^{-26}$ cm^3/s [75], which we use in Figure (2), allowing for a possible boost factor, as elaborated subsequently.

The $\mathcal{F}\text{-}SU(5)$ lightest neutralino composition is greater than 99% bino, therefore, we cannot neglect the quite small $\widetilde{\chi}\widetilde{\chi} \to Z\gamma$ annihilation cross-section $\langle \sigma v \rangle \sim 10^{-30}$ cm^3/s, about three orders of magnitude less than the FERMI-LAT telescope observations. On the other hand, a recent analysis [76] of extra-galactic clusters uncovering synonymous 130 GeV gamma-ray lines has determined an appropriate subhalo boost factor in this context of ~ 1000 relative to the galactic center. We do not consider it implausible that an overall unaccounted boost factor of similar magnitude might reconcile this apparent discrepancy of scale. For now, we are content to simply make note of the interesting correlation that

exists between 145 GeV $\mathcal{F}$-$SU(5)$ neutralino annihilations and the unexplained 130 GeV gamma-ray line observed by the FERMI-LAT space telescope, irrespective of the absolute $\langle \sigma v \rangle$ cross-section magnitude.

We include in Figure (2) the multi-axis χ^2 of Ref. [62], computed from those 8 TeV ATLAS multijet searches that display evidence of over-production above background expectations. The vertical yellow band in Figure (2) depicts the 2σ range around the χ^2 minimum computed from the nominal number of $\mathcal{F}$-$SU(5)$ simulated events times 0.50, bordered by the lower 2σ boundary at about $M_{1/2} \sim 660$ GeV. The Golden Strip is represented by the cross-hatched region, confined by the lower 2σ boundary on $Br(b \to s\gamma)$ at its lower $M_{1/2} \sim 545$ GeV limit, and by the lower 2σ boundary on Δa_μ at the Golden Strip's upper $M_{1/2} \sim 760$ GeV limit. Demonstrated in Figure (2) is the intersection of these two bands of model space defined by the 2σ observable regions of completely uncorrelated experiments, though apparently exhibiting interesting evidence of correlated behavior in a No-Scale $\mathcal{F}$-$SU(5)$ framework. To further heighten the intrigue, the 130-150 GeV LSP model space corresponding to the FERMI-LAT Space Telescope observations of a 130 GeV monochromatic gamma-ray line from the galactic center also very curiously lies snugly within the intersection of all experiments. Notice that the gluino and light stop mass scales are inserted at the bottom of Figure (2). Due to the characteristic rescaling property of No-Scale $\mathcal{F}$-$SU(5)$, a direct proportional relationship exists between the SUSY spectrum and gaugino $M_{1/2}$, permitting a simple visual inspection of the associated gluino and light stop masses for any specified $M_{1/2}$.

It is worth emphasizing again that all points delineated by the curves in each pane in Figure (2) are themselves the intersection of three critical parameters measured to high precision in current experiments, namely the 7-year WMAP relic density $0.1088 \le \Omega h^2 \le 0.1158$, a 124-127 GeV light Higgs boson mass, and a $172.2 \le m_t \le 174.4$ GeV top quark mass. Therefore, at the present time, we can find no experiment pertinent to the supersymmetric parameter space that is not in conformance with the narrow band of No-Scale $\mathcal{F}$-$SU(5)$ model space from $660 \lesssim M_{1/2} \lesssim 760$ GeV, which corresponds to sparticle masses of $133 \lesssim M(\widetilde{\chi}_1^0) \lesssim 160$ GeV, $725 \lesssim M(\widetilde{t}_1) \lesssim 845$ GeV, and $890 \lesssim M(\widetilde{g}) \lesssim 1025$ GeV. Such a mutual interrelation between all relevant experiments seems to strongly belie attribution to random stochastics.

The proximity of the 145-150 GeV LSP strip that resides within the theoretically and phenomenologically favored $\mathcal{F}$-$SU(5)$ parameter space defined by all model constraints, in

relation to the minimum of our multi-axis χ^2 curve, recalls to mind a very similar level of statistical adjacency shared by the updated χ^2 curves for the experimental Higgs boson mass measurements ($m_h \sim 125$ GeV) with the mass region theoretically and phenomenologically favored by electroweak precision measurements at $m_h = 94^{+29}_{-24}$ GeV [77]. The difference of about one standard deviation between the empirically measured Higgs boson mass and the electroweak precision favored region is roughly akin to the statistical margin separating the LHC SUSY multijet measurements and the optimum phenomenological $\mathcal{F}$-$SU(5)$ region, where we would assign a standard fluctuation width of about 60 GeV to deviations in the downward mass direction, and 200 GeV to the upper χ^2 median intersection. Thus, we may take great satisfaction that such a level of consistency is displayed between experiment and theory in $\mathcal{F}$-$SU(5)$, supported by relevant historical precedent.

As two points of potentially relevant interest, we must also remark in passing on recent developments regarding the measurement of the top quark mass and the strong coupling constant. An external study based on ATLAS inclusive jet cross section data [78] has suggested the value $\alpha_s(M_Z) = 0.1151$, which is slightly lower than the world central value of 0.1161 on which we above remarked. Also, the CMS Collaboration has recently announced [79] the world's single most precise top quark mass measurement at $m_h = 173.49 \pm 1.07$ GeV, with a central value slightly above the existing world average. Moreover, the latest measurements by ATLAS show central values of $m_t = 174.5$ GeV [80], $m_t = 174.9$ GeV [81], and $m_t = 175.2$ GeV [82], all modestly elevated above the world average central value. In Ref. [60], we investigated on the roles that a slightly elevated top quark mass, and a slightly reduced strong coupling could play in facilitating satisfaction of the central Higgs mass measurements in the range of 125–126 GeV, without resorting to an overly heavy squark spectrum or extremities in the error margins for the Higgs mass itself. The lowering of α_s while maintaining consistency with precision electroweak scale data is an accommodation to which the flipped $SU(5)$ GUT is particularly well historically adapted [83]. An interesting side effect of this modification is an escalation in the proton decay rate linked to a parallel reduction in the GUT scale M_{32}.

We close our discussion of Figure (2) by remarking on the striking familiarity of this figure to the correlation of predicted and observed light elemental abundances with the value of the baryon-to-photon ratio given by the observations of the Cosmic Microwave Background (CMB) by WMAP. The amazing consistency with which predictions of light element abun-

dances by Primordial Nucleosynthesis demonstrates with astronomical observations, while also compatible with the independently measured CMB, provide powerful corroboration of the Big Bang Theory. We envision a compelling parallel here amongst the synthesis of light elements predicted by Primordial Nucleosynthesis and observed by experiments, with the synthesis in an ubiquitous $\mathcal{F}$-$SU(5)$ structure in nature of all currently progressing experiments searching for physics beyond the Standard Model, to which we aptly offer the description *Primordial Synthesis*. Analogous to the consistency encountered between theory and experiment of light elemental abundances in Primordial Nucleosynthesis that provides a convincing connection to the Big Bang Theory, we suggest that the consistency revealed in Figure (2) between all the BSM experiments in No-Scale $\mathcal{F}$-$SU(5)$ Primordial Synthesis presents persuasive indications of BSM physics currently being probed at the LHC and indeed possibly all the experiments involved in searching for the parameters in Figure (2).

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